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Responses of Experimental Estuarine Communities to Continuous Chlorination

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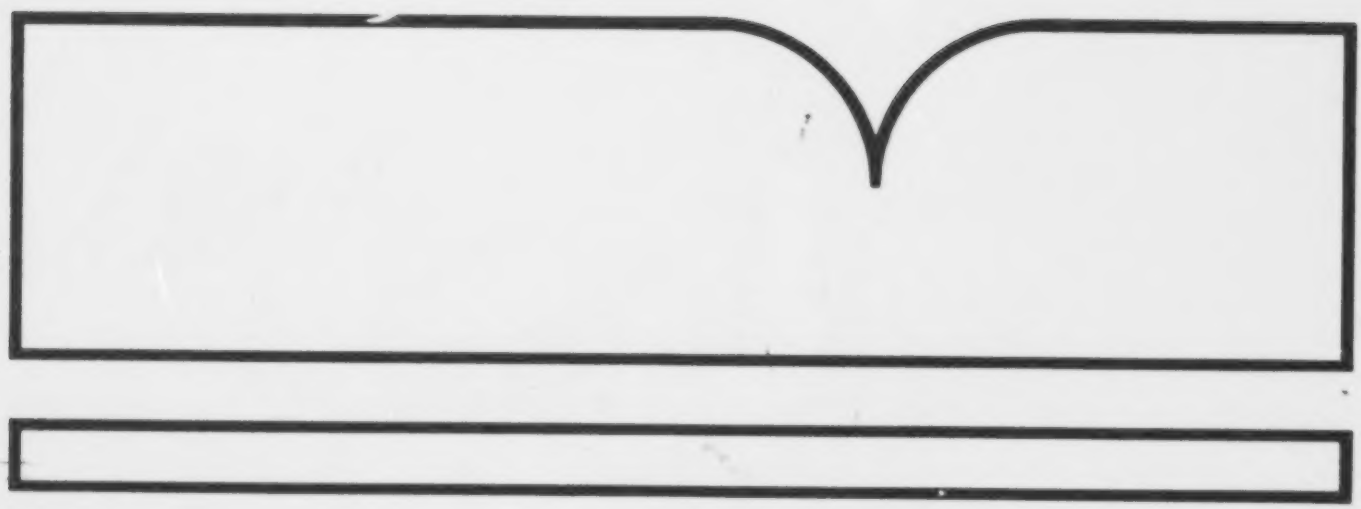

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16. ABSTRACT

The effects of continuous chlorination (as NaOCl) on estuarine benchic organisms were investigated with plankton-derived experimental communities. Twelve consecutive studies were conducted, each of which consisted of approximate 60 day colonization periods from flowing estuarine waters continuously receiving nominal 0.00, 0.47, 0.94, or 1.41 mg/liter chlorine produced oxidant (CPO). Compared to controls, short-term (60 day) effects of chlorination included elimination of dominant species, replacement of one dominant species by another, and increased toxic effects correlated with extreme cold weather. Long-term effects (pooled over the 27 month study) included changes in the overall community composition and 40% reduction in numbers of individuals in communities receiving chlorine. Total numbers of species recorded were unaffected by chlorination.

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Responses of Experimental Estuarine Communities to Continuous Chlorination

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Keywords: chlorine; benthos; estuaries; South Carolina

The effects of continuous chlorination (as NaOCl) on estuarine benthic organisms were investigated with plankton-derived experimental communities. Twelve consecutive studies were conducted, each of which consisted of approximately 60-day colonization periods from flowing estuarine waters that continuously received nominal concentrations of 0·00, 0·47, 0·94 or 1·41 mg chlorine-produced oxidant (CPO) l^{-1}.

Significant chlorination effects on numerical abundances of eight dominant species were detected in data pooled over the 12 consecutive studies, although only two species were significantly affected in proportional abundance. There was also a significant decline in total numbers of individuals collected in chlorinated communities. Significant differences in short-term community structures were found in only four of 12 experiments and were related to changes in species dominance and increased toxicity due to extreme cold weather.

Introduction

Chlorination is a widely used biocidal practice employed in the treatment of municipal wastes, industrial effluents and household disinfection, as well as in the control of fouling organisms in cooling waters of electric power generating stations. Chlorination in U.S. steam electric stations averaged $23{\cdot}6 \times 10^6$ kg $year^{-1}$ from 1969 through 1974 (Hamilton, 1978). Recent U.S. estimates of chlorination for disinfection and antifouling processes range upwards of 90×10^6 kg $year^{-1}$ (Macalady *et al.*, 1977; Jolley *et al.*, 1978). Chlorination of saline waters produces large quantities of halogenated compounds in coastal environments, the amounts and types of which are influenced by factors such as sunlight, entrained organics, ammonia content and salinity (Macalady *et al.*, 1977; Bean *et al.*, 1978; Carpenter & Macalady, 1978; Carpenter & Smith, 1978; Helz & Hsu, 1978; Helz *et al.*, 1978; Inman & Johnson, 1978). The effects of many of the individual chlorination byproducts are unknown, but progressively more interest has focused on overall effects of the chlorination process on aquatic communities.

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Deleterious effects from chlorination at power plant discharge sites have been reported in many field studies. Whereas zooplankton motility was not significantly reduced by chlorination at 1·00 mg chlorine-produced oxidant (CPO) l^{-1} (Davis & Jensen, 1975), considerable overall mortality of zooplankton in waters chlorinated at 0·5 to 10·0 mg CPO l^{-1} has been documented (Gentile *et al.*, 1976; Goldman & Davidson, 1977; Goldman *et al.*, 1978; Davis & Coughlan, 1978). The few laboratory and field studies of chronic chlorination at 0·25 to 5·60 mg CPO l^{-1} indicate lethal and sublethal effects on oysters (Scott & Middaugh, 1978) and on fouling communities (Turner *et al.*, 1948; Markowski, 1960).

Few quantitative assessments of the effects of continuous chlorination on benthic communities have been conducted. We report here a study in which we examined seasonal and long-term effects of chlorination on benthic communities developing from estuarine meroplankton. Studies of experimental communities are advantageous in incorporating many natural variables (physical and chemical processes, reproduction, migration, behavior, seasonal abundance and species interactions) while eliminating potential interference by certain system-induced variables found, for example, at a discharge site (thermal/chemical/nutrient additions, mechanical effects). Our intention was to conduct investigations which fell between the extremes of the rigorously controlled, single species bioassay and the on-site monitoring of a largely uncontrolled, multi-species assemblage in a discharge area.

Materials and methods

Benthic community response to chronic chlorination was determined by comparisons of numbers and species of macrobenthic organisms that colonized treated and untreated chambers. The experimental system was designed by Hansen (1974) and consisted of four groups of 10 adjacent plexiglass chambers, each 44 cm long, 9 cm wide and 14 cm deep. Water depth was maintained at 8 cm. A 2-cm layer of clean sand was added to each chamber at the onset of each study. The system was operated indoors, illuminated by low-level fluorescent lights (110 1-m candles, 8 h on; 16 h off) to limit algal growth.

Estuarine water that contained entrained planktonic organisms (eggs, larvae, juveniles) was pumped from 1 m below the surface of the North Edisto River at the Bears Bluff Field Station on Wadmalaw Island, 40 km south of Charleston, South Carolina, U.S.A. (lat. 32°40′N, long. 80°18′W). The water flowed continuously to a primary head box, where it was filtered through 1·6-mm mesh nylon screening to block entry of large detrital particles and small predators (shrimp, crabs, fishes) to the test chambers. After filtration, four adjacent stand pipes supplied water at a rate of 3 l min^{-1} to secondary head boxes atop each group of 10 chambers. Analytical grade NaOCl was continuously applied by syringe pumps at nominal concentrations of 0·00, 0·47, 0·94 or 1·41 mg CPO l^{-1} as the water left the primary head box. Water flow to each chamber was maintained at 200 ml min^{-1} by adjustable stand pipes in the secondary head boxes. Water exited from each chamber through a V-notch at the top of the end wall opposite the inflow area.

In this study, the chlorination concentrations are given in units of mg chlorine-produced oxidant (CPO) l^{-1}. Although an aqueous solution of NaOCl was the source of oxidative chlorine (HOCl and OCl^-), the chemical reactions cascading from the addition of this solution to seawater result in a variable mixture of many oxidative species. 'Nominal CPO' concentrations were thus designated rather than 'measured' chlorine residuals, because of the uncertain identity and possible non-detection of oxidants measured by the standard chlorination analysis of amperometric titration.

Experiments were conducted from August 1975 to September 1977. Temperature and salinity were monitored daily. Container colonization was allowed for approximately 2 months (mean, 57 days; range, 42 to 72 days) for twelve successive studies. After each colonization period, each chamber was scraped and the entire contents siphoned into a 0·500-mm mesh screen, preserved in 7% formalin, and subsequently sorted and identified.

Results

Physical and chemical characteristics

A summary of experimental dates, durations and temperature and salinity measurements is given in Table 1. Concentrations of residual chlorine-produced oxidants were not measured in this study. However, Table 1 includes CPO residuals predicted by regression analyses of measurements made in a partially concurrent study (employing the same water source but a different apparatus) on the range of nominal 0·18 to 5·60 mg CPO l^{-1} (as NaOCl) from 24 September 1976 to 27 September 1977 (G. I. Scott, U.S. Environmental Protection Agency, Bears Bluff Field Station, personal communication). Potential residual CPO concentrations during each of the 12 experiments were best predicted by exponential equations of the form $Y=Ae^{BX}$ (where Y=residual CPO, X=nominal CPO addition) which had coefficients of determination (R^2) values of 0·82 to 0·95.

TABLE 1. Physical and chemical characteristics of the container system during 12 consecutive studies. Residual oxidant concentrations were predicted for nominal CPO concentrations by regression. Expt.=sequential experiment number

Expt.	Exposure dates	Duration (days)	Temp. (°C)		Sal. (‰)		Residual CPO predicted from nominal CPO (mg l^{-1})			
			$\bar{x}$	range	$\bar{x}$	range	0·00	0·47	0·94	1·41
1	12 Aug.–29 Sept. 1975	42	29	23–33	26	20–29	0	0·08	0·12	0·18
2	1 Oct.–28 Nov. 1975	59	22	11–29	28	26–30	0	0·04	0·09	0·18
3	5 Dec. 1975–6 Feb. 1976	63	12	5–20	27	25–29	0	0·15	0·20	0·26
4	11 Feb.–14 Apr. 1976	59	19	10–23	27	24–29	0	0·15	0·20	0·28
5	21 Apr.–18 June 1976	58	25	19–31	27	25–30	0	0·12	0·16	0·20
6	22 June–18 Aug. 1976	55	30	23–33	23	18–26	0	0·10	0·13	0·16
7	27 Aug.–20 Oct. 1976	56	27	21–31	27	25–29	0	0·05	0·08	0·14
8	26 Oct.–20 Dec. 1976	63	13	7–18	28	26–30	0	0·06	0·10	0·19
9	23 Dec. 1976–23 Feb. 1977	53	10	0–21	24	18–26	0	0·14	0·18	0·26
10	6 Mar.–27 Apr. 1977	53	22	16–26	22	20–26	0	0·16	0·22	0·29
11	10 May–21 June 1977	43	29	24–31	27	26–28	0	0·12	0·16	0·20
12	4 July–13 Sept. 1977	72	30	24–33	29	26–31	0	0·10	0·13	0·17

Analysis of system design

The apparatus used in this study was previously employed by Hansen (1974) and Tagatz *et al.* (1978). However, these investigators did not report data on the replicability of samples nor did their experiments include seasonal factors. Several analyses were employed to determine if the test system in our study suffered from inherent design bias. We first examined the numbers of species and individuals recorded in each replicate of a given CPO regime for each of the 12 collections. By analysis of variance (ANOVA), no significant ($P>0·05$) differences in numbers of species or individuals among like replicates were found, perhaps due to seasonal variability in abundances of organisms.

TABLE 2. Organisms collected in control containers in 12 successive studies. Each value is the sum of 10 replicates. Grand totals are given at right. Experimental dates are given in Table 1

Species	Experiment 1	2	3	4	5	6	7	8	9	10	11	12	Total
Annelida													
Ampharete sp.	—	—	3	23	114	—	—	—	—	1	—	—	141
Heteromastus filiformis	—	—	—	—	—	—	—	—	47	3	9	—	59
Hydroides dianthus	—	—	—	—	—	—	—	—	—	—	1	—	1
Nereis succinea	3	—	—	1	1	1	5	—	—	1	7	—	19
Nereis sp.	—	—	—	—	8	—	—	—	—	—	—	1	9
Pherusa inflata	—	—	—	—	1	—	—	—	—	—	—	—	1
Pista sp.	1	7	—	—	402	44	1	2	—	—	1	28	486
Polydora websteri	—	—	—	—	—	2	—	2	1	—	—	—	5
Mollusca													
Brachidontes exustus	—	1	—	2	1	—	—	—	—	2	—	—	6
Crassostrea virginica	—	—	—	—	1	—	—	—	—	—	—	—	1
Hydrobia sp.	1	—	—	—	—	—	—	—	—	—	—	—	1
Lyonsia hyalina	—	—	1	—	—	—	—	—	—	—	—	—	1
Macoma tenta	3	4	54	35	59	—	1	—	—	1	8	1	166
Mulinia lateralis	—	—	—	—	4	—	—	—	—	—	—	—	4
Arthropoda													
Alpheus heterochaelis	1	—	—	—	—	—	—	—	—	—	—	—	1
Anoplodactylus parvus	3	1	—	—	1	—	—	1	2	1	1	23	33
Balanus balanoides	—	—	6	—	—	—	—	—	—	1	—	—	7
Caprella equilibra	2	7	13	—	1	—	—	1	—	—	—	—	24
Corophium acherusicum	21	24	123	4	12	—	3	51	—	—	—	8	246
Decapod larva	—	—	—	—	—	—	—	—	—	—	—	1	1
Edotea montosa	—	—	—	4	13	—	—	—	—	—	—	1	18
Haustorius sp.	—	—	—	—	—	—	—	15	—	—	—	—	15
Hemiaegina minuta	—	—	—	—	—	—	—	—	17	—	—	—	17
Leucon americanus	—	—	1	—	1	—	—	—	—	—	—	—	2
Melita nitida	48	66	1	1	7	1	2	16	9	29	124	50	354
Oxyurostylus smithi	—	—	—	1	—	—	—	—	—	—	—	—	1
Panopeus herbstii	—	—	—	—	—	—	1	—	—	—	—	—	1
Parapleustes aestuarius	—	—	—	—	—	—	—	—	—	1	—	—	1
Stenothoe georgiana	—	1	6	1	—	—	—	—	1	—	—	—	9
Other phyla													
Anemone	—	2	—	—	—	—	—	—	—	—	2	1	5
Gobiosoma bosci	—	—	—	—	1	—	—	—	—	—	—	—	1
Hemipholus elongata	—	1	—	—	—	—	—	—	—	—	—	—	1
Molgula manhattensis	16	—	—	2	2	1	16	8	—	358	5	—	408
Number of species	10	10	9	10	17	5	7	8	6	10	9	9	33
Number of individuals	99	114	208	74	629	49	29	96	77	398	158	114	2045

We then examined total numbers of species and individuals collected in each replicate summed over 12 collections. In terms of numbers of species, no significant (χ^2, $P>0.05$) differences were found among the 10 replicates in a given CPO regime. However, in each of the four CPO regimes, there was at least one replicate in a series of 10 that contained a significantly (χ^2, $P<0.05$) different number of individuals than other replicates after 12 collections. A comparison of the numbers of individuals in replicates 1 to 5 (nearest to water inflow) with those in replicates 6 to 10 (farthest from water inflow) of each CPO regime indicated significantly (ANOVA, $P<0.05$) higher numbers of individuals in replicates 1 to 5. Thus, the system design of linear water delivery over consecutive inlet ports produced a long-term bias in the number of individuals per replicate. Since each series of 10 replicates behaved similarly and since no bias in numbers of species or individuals was

TABLE 3. Organisms collected in containers that received nominal 0·47 mg CPO l^{-1} in 12 successive studies. Other information as in Table 2

Species	Experiment 1	2	3	4	5	6	7	8	9	10	11	12	Total
Annelida													
Ampharete sp.	—	—	—	1	4	—	—	—	—	—	—	—	8
Eteone heteropoda	—	—	—	2	—	—	—	—	—	—	—	—	2
Heteromastus filiformis	—	—	—	—	—	—	—	—	56	2	11	—	69
Nepthys incisa	—	—	—	—	—	—	—	—	—	2	—	—	2
Nereis succinea	2	—	—	—	—	7	2	1	—	—	28	4	44
Nereis sp.	—	—	—	—	2	—	—	—	—	—	—	—	2
Pectinaria gouldii	—	—	—	—	1	—	—	—	—	—	—	—	1
Pista sp.	1	14	—	—	296	63	4	—	—	—	—	10	388
Polydora websteri	—	—	—	—	—	—	—	1	—	—	—	—	1
Mollusca													
Brachidontes exustus	1	—	—	—	1	—	—	—	—	—	—	—	2
Hydrobia sp.	—	—	—	—	—	2	—	—	—	—	—	—	2
Macoma tenta	2	9	18	24	34	—	—	1	—	—	—	2	90
Mulinia lateralis	1	—	—	—	—	—	—	—	—	—	—	—	1
Nucula proxima	—	—	—	—	1	—	—	—	—	—	—	—	1
Puncturella sp.	—	1	—	—	—	—	—	—	—	—	—	—	1
Vitrinella sp.	—	—	—	—	—	6	—	—	—	—	—	—	6
Arthropoda													
Anoplodactylus parvus	1	—	2	—	—	—	—	1	2	—	—	6	12
Caprella equilibra	1	4	5	—	—	—	—	2	—	—	—	—	12
Corophium acherusicum	9	13	49	3	4	—	—	63	—	1	—	2	144
Edotea montosa	—	—	—	—	9	—	—	—	—	1	—	1	11
Haustorius sp.	—	—	—	—	—	—	—	34	—	—	—	—	34
Hemiaegina minuta	—	—	—	—	—	—	—	4	1	—	—	—	5
Leucon americanus	—	—	1	—	—	—	—	—	—	—	—	—	1
Melita nitida	92	58	1	1	5	—	—	11	3	1	152	83	407
Mucrogammarus mucronatus	—	—	—	—	—	—	—	—	—	1	—	—	1
Panopeus herbstii	1	—	—	—	—	—	—	—	—	—	—	—	1
Stenothoe georgiana	—	1	2	1	—	—	—	—	1	—	—	—	5
Other phyla													
Anemone	—	—	—	—	—	1	—	—	—	—	—	—	1
Molgula manhattensis	5	—	—	—	—	—	—	—	—	—	—	—	5
Number of species	12	7	7	6	10	5	2	8	5	7	3	8	29
Number of individuals	117	100	78	35	357	79	6	114	66	9	191	109	1261

perceived on a collection-by-collection basis, we felt that the experimental procedure was basically sound and that representative results were obtained. The system was redesigned by Tagatz *et al.* (1979), eliminating the bias caused by linear water delivery.

Summed chlorination effects

The data from the 12 consecutive experiments were pooled to examine average community effects of chlorination, since no single community was allowed to develop for more than 72 days. A total of 49 species and 5686 individuals were collected over the 12 experiments (Tables 2 to 5). In this study, chlorination of estuarine waters produced little effect on total numbers of species: each CPO regime had similar totals (33, 29, 30 and 31 species in nominal 0·00, 0·47, 0·94 and 1·41 mg CPO l^{-1}, respectively). Many of these species were 'rare', being collected in small numbers once or twice. Only 17 species were common to all CPO regimes. Certain of the dominant species [*Corophium acherusicum* and *Caprella equilibra* (amphipods), *Macoma tenta* (bivalve), *Pista* sp. and *Ampharete* sp. (polychaetes)] were more abundant in the first six collections in 1975–1976, whereas other dominants

TABLE 4. Organisms collected in containers that received nominal 0·94 mg CPO l^{-1} in 12 successive studies. Other information as in Table 2

Species	Experiment 1	2	3	4	5	6	7	8	9	10	11	12	Total
Annelida													
Ampharete sp.	—	—	—	5	—	—	—	—	—	—	—	—	5
Heteromastus filiformis	—	—	—	—	—	—	—	—	59	2	5	1	67
Nepthys incisa	—	—	—	—	—	—	—	—	—	2	—	—	2
Nereis succinea	3	1	—	—	—	8	6	3	—	—	33	2	56
Nereis sp.	—	—	—	—	1	—	—	—	—	—	—	—	1
Pherusa inflata	—	—	—	—	1	—	—	—	—	—	—	—	1
Pista sp.	—	38	1	—	232	87	4	3	—	—	—	29	394
Polydora websteri	—	—	—	—	—	—	—	3	2	—	—	—	5
Mollusca													
Hydrobia sp.	1	—	—	—	—	—	—	—	—	—	—	—	1
Lyonsia hyalina	—	—	—	1	—	—	—	—	—	—	—	—	1
Macoma tenta	—	4	8	18	63	1	—	—	—	—	—	2	96
Nucula proxima	—	—	—	—	1	—	—	—	—	—	—	—	1
Nudibranch	—	—	—	—	—	1	—	—	—	—	—	1	2
Vitrinella sp.	—	—	—	—	—	—	—	—	—	—	—	2	2
Arthropoda													
Anoplodactylus parvus	—	—	3	1	—	—	—	—	1	—	—	7	12
Balanus balanoides	—	—	3	1	—	—	—	—	—	—	—	—	4
Caprella equilibra	—	6	4	2	1	—	—	1	—	—	—	—	14
Corixidae	—	—	—	—	—	—	—	—	—	—	—	1	1
Corophium acherusicum	19	13	83	2	9	2	—	72	—	—	—	—	200
Decapod larva	1	—	—	—	—	—	—	—	—	—	—	—	1
Edotea montosa	—	—	—	3	6	—	—	—	—	2	1	—	12
Haustorius sp.	—	—	—	—	—	—	—	35	—	—	—	—	35
Hemiaegina minuta	—	—	—	—	—	—	—	—	—	2	—	—	2
Melita nitida	80	31	2	2	2	1	—	9	4	3	48	37	219
Mucrogammarus mucronatus	—	—	—	—	—	—	—	—	—	—	—	2	2
Panopeus herbstii	—	—	—	—	—	—	—	—	—	—	—	1	1
Parapleustes aestuarius	—	—	—	—	—	—	—	—	—	—	2	—	2
Stenothoe georgiana	—	—	5	—	—	—	—	—	—	—	—	—	5
Other phyla													
Anemone	1	—	—	—	—	—	—	—	—	—	—	2	3
Hemipholus elongata	—	—	—	—	—	—	—	—	—	—	—	1	1
Number of species	6	6	8	9	9	6	2	7	5	4	5	13	30
Number of individuals	105	93	109	35	316	100	10	126	68	9	89	88	1148

[*Molgula manhattensis* (tunicate), *Anoplodactylus parvus* (pycnogonid), *Haustorius* sp. and *Hemiaegina minuta* (amphipods), *Heteromastus filiformis* and *Nereis succinea* (polychaetes)] were more abundant in the last six collections of 1976–1977. In contrast to numbers of species, total numbers of individuals were significantly (χ^2, $P<0{\cdot}05$) affected by chlorination, since chlorinated communities contained 38 to 44% fewer organisms than controls (2045, 1261, 1148 and 1232 individuals in 0·00, 0·47, 0·94 and 1·41 mg CPO l^{-1} respectively.

The responses to chlorination of the nine most numerous species common to all CPO regimes are given in Table 6. Compared to controls, chlorination significantly (χ^2, $P<0{\cdot}05$) depressed the numbers of *Ampharete*, *Molgula* and *Macoma* in three concentrations, and *Pista*, *Corophium* and *Melita nitida* (amphipod) in two concentrations. However, when standardized to a percentage of the total fauna, only *Ampharete* and *Molgula* were significantly (χ^2, $P<0{\cdot}05$, arcsine transformation) lower in abundance, being almost entirely eliminated by chlorination with NaOCl. Chlorination resulted in significantly (χ^2, $P<0{\cdot}05$) higher numbers of *Haustorius* and *Nereis succinea*, while on a percentage basis these two

TABLE 5. Organisms collected in containers that received nominal 1·41 mg CPO l^{-1} in 12 successive studies. Other information as in Table 2

Species	Experiment 1	2	3	4	5	6	7	8	9	10	11	12	Total
Annelida													
Ampharete sp.	—	—	—	3	—	—	—	—	—	—	—	—	3
Arabella mutans	—	—	—	—	—	—	—	—	—	1	—	—	1
Eteone heteropoda	—	—	—	—	—	—	—	1	—	—	—	—	1
Heteromastus filiformis	—	—	—	—	—	—	—	—	52	2	5	—	59
Nepthys incisa	—	—	—	—	—	—	—	—	—	2	—	—	2
Nereis succinea	3	—	—	—	—	18	6	—	—	—	14	2	43
Nereis sp.	—	—	—	—	6	—	—	—	—	—	—	—	6
Pista sp.	1	22	2	—	351	23	7	—	—	—	2	70	478
'Polychaete A'	—	—	—	—	1	—	—	—	—	—	—	—	1
'Polychaete B'	—	—	—	—	—	—	2	—	—	—	—	—	2
Polydora websteri	1	—	—	—	—	—	2	3	1	—	—	—	7
Mollusca													
Acteocina canaliculata	—	1	—	—	1	—	—	—	—	—	—	—	2
Brachidontes exustus	—	—	—	—	1	—	—	—	—	—	—	—	1
Laevicardium laevigatum	—	—	—	—	1	—	—	—	—	—	—	—	1
Lyonsia hyalina	—	—	—	1	—	—	—	—	—	—	1	—	2
Macoma tenta	1	3	14	23	48	—	—	—	—	—	—	2	91
Nudibranch	—	—	—	—	—	—	—	—	—	—	—	1	1
Arthropoda													
Anoplodactylus parvus	1	1	—	1	—	—	—	—	1	—	—	13	18
Balanus balanoides	—	—	—	1	—	—	—	—	—	—	—	—	1
Caprella equilibra	2	9	7	1	—	—	—	1	—	—	—	—	20
Corophium acherusicum	8	11	71	5	3	—	4	106	1	1	—	—	210
Edotea montosa	—	—	—	6	3	—	—	—	—	1	—	1	11
Haustorius sp.	—	—	—	—	—	—	—	23	—	—	—	—	23
Hemiaegina minuta	—	—	—	—	—	—	—	—	2	1	—	—	3
Leucon americanus	—	—	—	1	1	—	—	—	—	—	—	—	2
Melita nitida	145	18	1	4	—	—	2	17	1	1	20	16	225
Sesarma reticulatum	—	—	—	—	—	—	—	—	—	—	1	—	1
Stenothoe georgiana	—	—	5	6	—	—	—	—	—	—	—	—	11
Other phyla													
Anemone	—	—	—	—	—	—	—	—	—	—	—	2	2
Hemipholus elongata	—	1	—	—	—	—	—	—	—	—	—	—	1
Molgula manhattensis	—	—	—	1	—	—	—	—	—	—	—	—	1
Turbellaria	1	—	—	—	—	—	—	—	1	—	—	—	2
Number of species	9	8	6	12	10	2	6	6	7	7	6	8	31
Number of individuals	163	66	100	54	416	41	23	151	59	9	43	107	1232

species plus *Pista*, *Corophium* and *Heteromastus* increased (although not significantly) in relative abundance in chlorinated communities, as compared with controls.

Short-term chlorination effects

Our previous analyses did not treat the seasonality of the colonizing faunas. The seasonal factor is important in determining the community composition and structure observed on any given date. Chlorination would also be expected to have seasonal effects (Scott & Middaugh, 1978), since the predicted residual CPO concentrations (Table 1) show seasonal fluctuations. Possible differences in community structure were investigated by examination of the degree of correlation in the distribution of numbers of individuals among the various taxa found on each sampling date. In eight of 12 collections there were no significant differences in correlations among controls and the three treatment concentrations. Significant

TABLE 6. Comparison of dominant species in control and chlorinated containers summed over 12 collections. No. = number of individuals, % = percentage of total numbers. Asterisks (*) indicate significant differences from controls by χ^2 ($P<0.05$). The arcsine transformation was used in testing percentages

	Nominal CPO (mg l^{-1})							
	0·00		0·47		0·94		1·41	
Species	No.	%	No.	%	No.	%	No.	%
Pista sp.	486	23·8	388*	30·8	394*	34·3	478	38·8
Molgula manhattensis	408	20·0	5*	0·1*	0	0·0*	1	0·1*
Melita nitida	354	17·3	407	32·3	219*	19·1	225*	18·3
Corophium acherusicum	246	12·0	144*	11·4	200*	17·4	210	17·0
Macoma tenta	166	8·1	90*	7·1	96*	8·4	91*	7·4
Ampharete sp.	141	6·9	8*	0·6*	5*	0·4*	3*	0·2*
Heteromastus filiformis	59	2·9	69	5·5	67	5·8	59	4·8
Nereis succinea	19	0·9	44*	3·5	57*	5·0	43*	3·5
Haustorius sp.	15	0·7	34*	2·7	35*	3·1	23	1·9
All other species	151	7·4	72	5·7	75	6·5	99	8·0
Total	2045		1261		1148		1232	

($P<0.05$) differences in community structure were indicated in August 1976, October 1976, April 1977 and September 1977.

In August 1976, the community that developed in nominal 1·41 mg CPO l^{-1} was distinct from all other communities. It was species-poor (2) and was characterized by an increased abundance of *Nereis succinea* (44% of the fauna) relative to *Pista* (56% of the fauna), whereas other communities were relatively species-rich (5–6) and were dominated by *Pista* (80–90% of the fauna) while *Nereis succinea* was rare. In October 1976, the control community was distinct from the otherwise closely-correlated chlorinated communities. This difference was due to the abundance of *Molgula* (55% of the fauna) only in controls and to relatively large *Pista* populations in the chlorinated systems (3% of the control fauna, 30–67% in others). In April 1977, following a severe winter when water temperatures declined to 0 °C, all four communities were distinct from each other. The control community was dominated by *Molgula* (90% of the fauna) and contained relatively large numbers of *Melita*. The chlorinated communities were numerically impoverished (each had only nine individuals) and showed little correlation in species composition. In September 1977, the community exposed to 1·41 mg CPO l^{-1} was distinct from the other three closely-correlated communities because of the domination by *Pista* (65% of the fauna) much more so than in other communities (9–33% of the faunas) and the decline of *Melita* (15% of the fauna) where it was otherwise abundant (42–76% of the faunas).

Discussion

At present, little research has been directed towards analysing community-level responses to chronic chlorination. The majority of the investigations have been either laboratory studies of acute toxicity or short-term studies at power plant discharge sites. Galtsoff (1946) found American oysters (*Crassostrea virginica*) sensitive to 0·01 to 0·2 mg free chlorine l^{-1} after 48 h, whereas Bongers *et al.* (1977) reported little mortality of adult oysters exposed to 0·035 to 0·085 mg total residual oxidant (TRO, equivalent to CPO) l^{-1} for 15 days. Waugh (1964) noted that barnacle (*Elminius modestus*) nauplii suffered heavy mortality

and reduced growth of survivors on exposure to 2·0 mg total residual chlorine (TRC, equivalent to CPO) l^{-1} for 10 min. McLean (1973) found that acute exposure of various invertebrates to 2·5 mg CPO l^{-1} for 5 min, followed by return to non-chlorinated water, caused heavy mortality in 3 to 96 h. Roberts *et al.* (1975) and Thatcher (1978) demonstrated 48- or 96-h TL50 values of 0·001 to 1·418 mg TRC l^{-1} for several coastal invertebrate species. Chlorination of seawater at 0·064 to 1·00 mg CPO l^{-1} resulted in reduced fertilization success and spermicidal effects after 5-min exposures in three invertebrate species (Muchmore & Epel, 1973).

In the present study, chlorination had an inconsistent impact on the colonization and development of estuarine communities. Short-term seasonal effects occurred sporadically (only in four of 12 experiments), but included elimination of dominant species (*Molgula*, *Ampharete*), replacement of one dominant species by another (*Melita* by *Pista*, or *Pista* by *Nereis*) and the interaction of extreme cold weather with chlorination to produce higher toxicity. Analysis of the pooled data of 12 consecutive studies showed no chlorination effects on numbers of species recorded and only two species whose proportional contributions to the total faunas were significantly reduced by chlorination. However, a general decline in the total numbers of individuals recorded was caused by chlorination. Our findings of inconsistent chlorination impact may be due to several factors, including small numbers of colonizing organisms, short colonization periods and water quality parameters such as salinity, ammonia content and entrained organics which were not controlled.

An interesting observation was the lack of a linear or gradient response by developing communities to increasing CPO levels. Instead, an abrupt 38 to 44% decline in numbers was found in chlorinated systems, as compared to controls. The region bounded by the controls and this 0·47 mg CPO l^{-1} 'threshold' is currently under investigation with another experimental community system (Davis *et al.*, 1977), in which the community responses to nominal concentrations of 0·000, 0·125, 0·250 and 0·500 mg CPO l^{-1} are being studied.

The experimental community approach to analysing the effects of chlorination can eliminate specific interfering variables, such as mechanical damage to organisms and additive/synergistic effects of thermal elevation of cooling waters, often present at power plant discharge sites. Since the organisms that colonized our system are meroplanktonic, this design is a logical simplification of on-site plankton studies relative to the objective of chlorination applications. The overall results of the present study document numerical decreases in benthic communities and elimination of certain sensitive species due to chlorination which generally agree with on-site studies (Gentile *et al.*, 1976; Goldman & Davidson, 1977; Goldman *et al.*, 1978; Davis & Coughlan, 1978). Concurrent analyses of chlorination-induced depression of microplanktonic (0·22 to 110 μ) ATP concentrations in this experimental system (Erickson & Foulk, 1980) were also in agreement with field studies (Gentile *et al.*, 1976).

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